«Localization of radioactive materials and reactor core 4 Ch NPP – system for dust suppression of radioactive aerosols»

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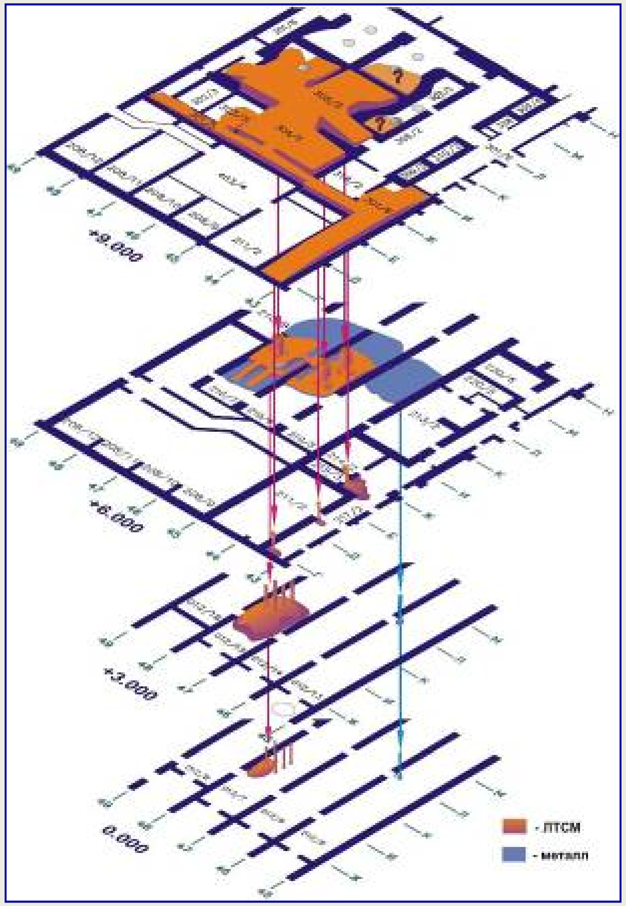
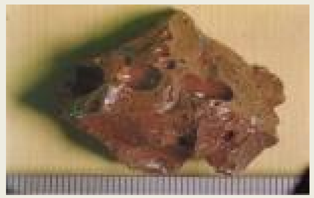
Nuclearly hazardous materials inside «Shelter» object

Currently, inside the «Shelter» object there are nuclear fuel modifications, which have produced in the course of accident's active stage proceeding during interaction of this fuel with structural materials, dynamic and heat effect of explosion, as well as uranium dioxide oxidation by contacting with air oxygen. Three modifications can be separated, in which the main mass of irradiated nuclear fuel (INF) is contained : reactor core fragments (RCF), fuel particles (fuel dust) and lava-like fuel-containing materials (LFCM).



Scheme of lava and melted metal spreading.

LFCM cluster on the first floor of pressure suppression pool (porous ceramics)



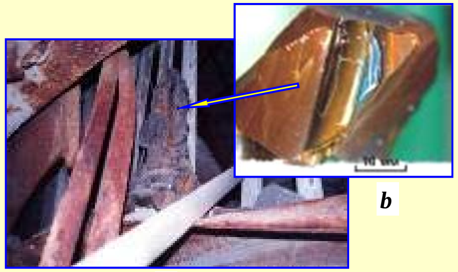
LFCM cluster on the second floor of pressure suppression pool (brown ceramics)

LFCM cluster of room 210/7 –
steam-distributing (brown ceramics)

LFCM cluster of room 210/6 –
steam-distributing (black ceramics)

LFCM cluster (black ceramics) in room 304/3

LFCM cluster (black ceramics)
in room 217/2

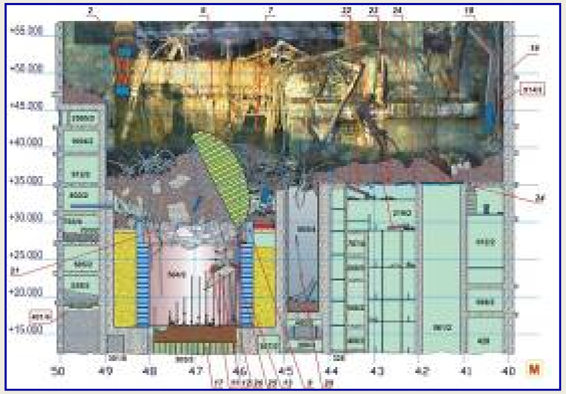


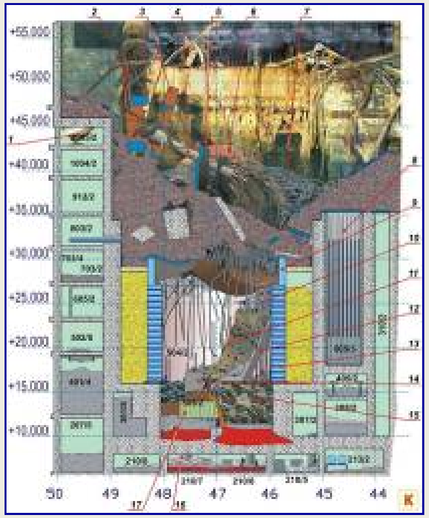
b

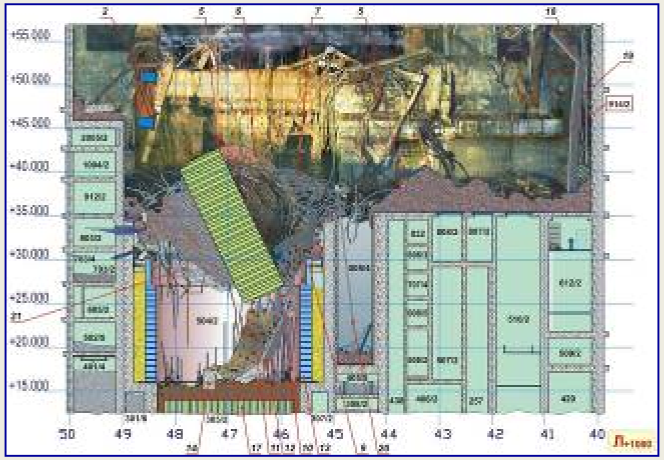
a

a- «stalagmite», b –
specimen of polychromatic
LFCM in reactor vault

Reconstruction of ruinations in rooms of destroyed Unit 4 and FCM layout places







1- environmental suit of reloading machine (RM);
2- RM bridge;
3- RM carriage;
4- reloading machine (RM);
5- diagnostic bouy;
6 – reactor top metalware – scheme «E»;
7- fuel channels («Elena hair»);
8- cassettes with spent nuclear fuel;
9- water tank of biological protection – scheme «D»;
10- fuel channels;
11- metal encasement of heat protection of separators box;
12- inclined standing ferroconcrete plate (fragment of separators box wall);
13- water tank of biological protection – scheme «Л»;
14- ferroconcrete structure;
15- «loose» FCM wall;
16- steam-discharging valve;
17- scheme «OR»;
18- beams of former Central Hall roofing;
19- cassettes with fresh fuel;
20- diagnostic «Needle»;
21- pipes of upper steam-water pipeline (SWP);
22- ferroconcrete plates, which came in room 219/2 from Central Hall;
23- gaps in room laying under Central Hall;
24- damages of floor overlap of Central Hall;
25- stalagmite (LFCM);
26- stalactite (LFCM);

- ferroconcrete of building structures;

metalwares;

concrete of 1986 year;

sand-gravel filling;

obstruction in Central Hall and other ooms;

obstruction and FCM in room 305/2;

LFCM;

melted and solidified metal;
«loose» FCM.

Composition of different modifications of Chernobyl lavas

LFCM type	Main oxides, mass. %													
	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	TiO_2	ZrO_2	BaO	UO_2	MnO	Cr_2O_3	NiO
black ceramics 304/3	70,6	7,4	0,25	0,23	3,9	6,7	6,2	0,21	5,8	0,13	4,3	1,9	0,30	$1{,}2 \cdot 10^{-3}$
black ceramics 217/2	66,6	8,7	0,40	0,36	3,8	8,5	5,6	0,27	5,8	0,15	5,0	3,8	0,33	0,19
black ceramics 210/6	62,1	7,2	2,91	2,63	5,1	6,0	5,2	0,19	5,5	0,18	5,8	0,40	0,40	0,39
brown ceramics 210/7	64,0	6,8	0,64	0,57	7,0	6,7	5,4	0,24	6,6	0,19	9,4	0,53	0,39	0,36

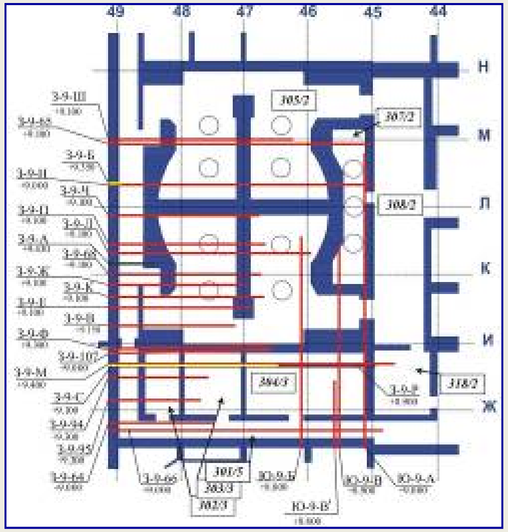
Colour and physicochemical properties of Chernobyl lavas are defined by uranium dioxide contained in them.

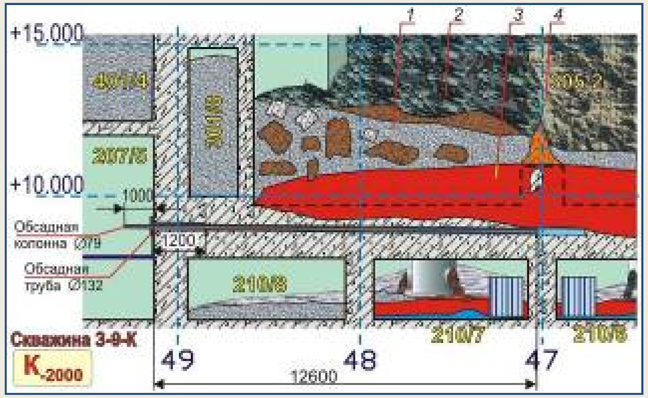
Study of LFCM have demonstrated that they are a product of complicated interactions of nuclear fuel and structural materials of reactor.

LFCM represents a heterogenous solid solution, whose «dilutant» is glass-like silicate matrix with large amount of diverse impurities.

LFCM contains a significant part of uranium, which was in core before the accident, as well as a considerable part of radionuclides (not less than 2/3 of those generated in reactor).

Boreholes within monitoring system of SO fuel-containing materials





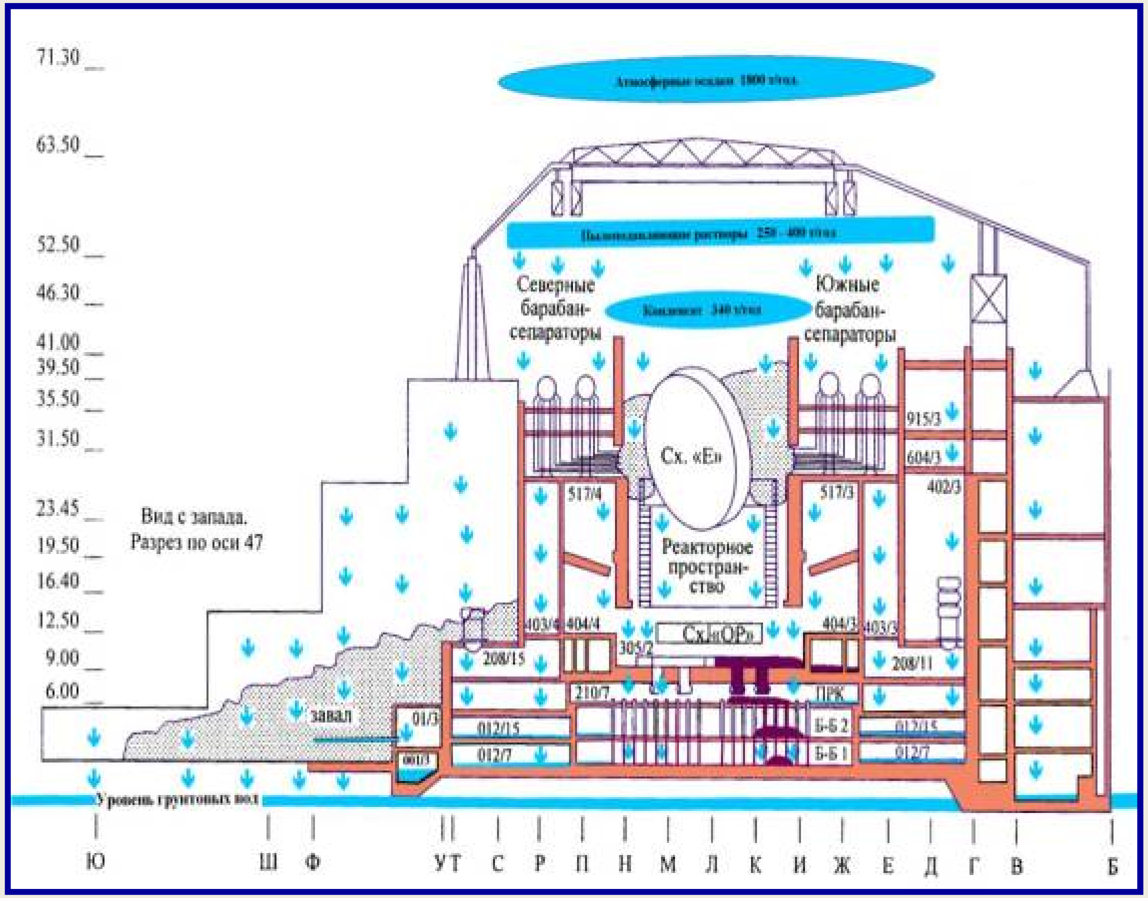
1 – concrete of 1986 year; 2 – obstruction containing FCM; 3 – assumed boundaries of LFCM spreading; 4 – loose FCM.

No	Sampling place, coordinates	Description of sample	U, %
1	47_{-400}, $К_{-2000}$, mark +9.100	Metal	0,6
2	47_{-400}, $К_{-2000}$, mark +9.100,	Graphite	0
3	47_{-400}, $К_{-2000}$, mark +9.100	Concrete fused	4,2
4	47_{-400}, $К_{-2000}$, mark +9.100	Concrete grey-black	0
5	47_{-1600}, $К_{-2000}$, mark +9.100	Concrete fused	4,7
6	47_{-1600}, $К_{-2000}$, mark +9.100	Sand	5,3
7	47_{-1600}, $К_{-2000}$, mark +9.100	Fused mass (concrete)	4,9
8	$47_{-1600}/47_{-400}$, $К_{-2000}$, mark +9.100	Black smoked mass, looking like concrete	8,8
9	47_{+800}, $К_{-2000}$, mark +9.100	Black sand	4,5
10	47_{+800}, $К_{-2000}$, mark +9.100	Concrete	0,3

To evaluate the occurrence geometry and conditions of fuel-containing materials (FCM) in SO sub-reactor rooms 305/2 and 304/3 beginning from 1988 year, investigation boreholes were drilled in these rooms' direction.
Study of core material retrieved from boreholes on mark +9.000 - +12.000 and subsequently performed borehole measurements had allowed obtaining the main mass of information on FCM located on sub-react plate and in this plate solid.

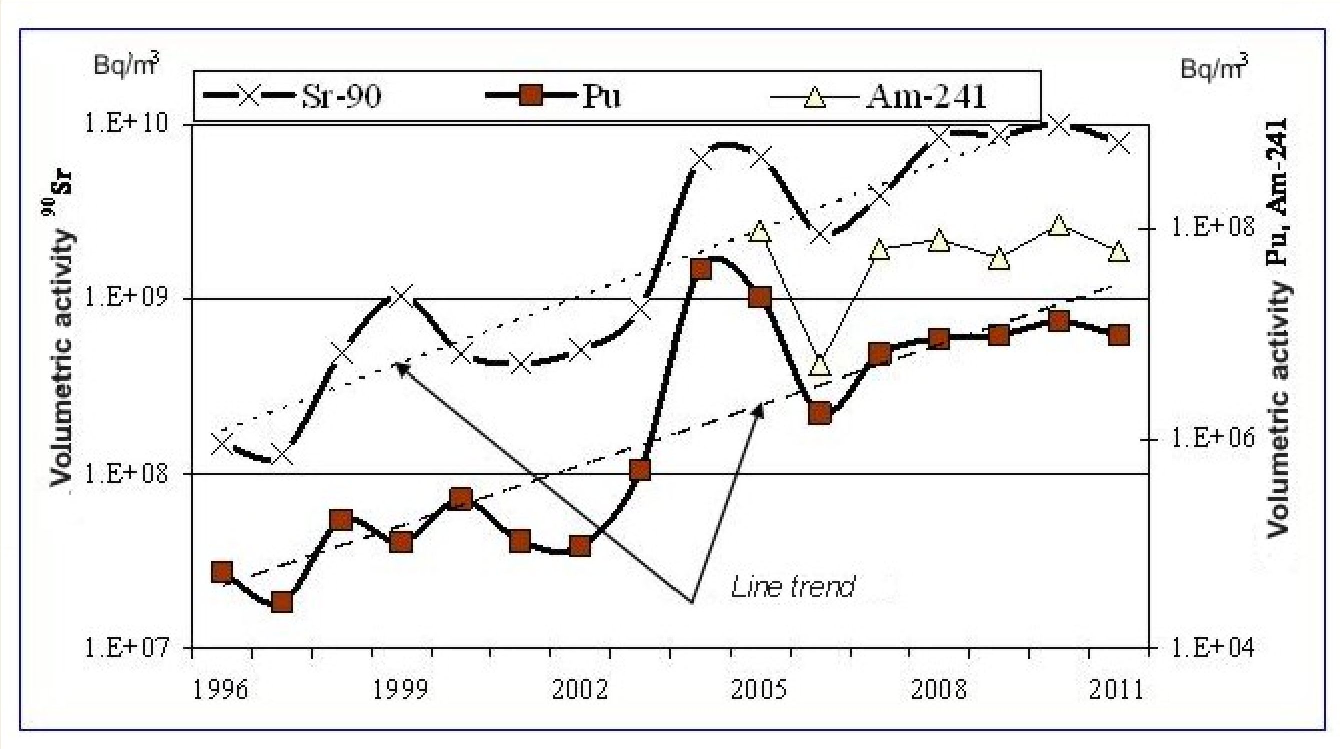
Monitoring of nuclear and radioecological safety of «Shelter» object

- **Monitoring of state of liquid radioactive wastes**

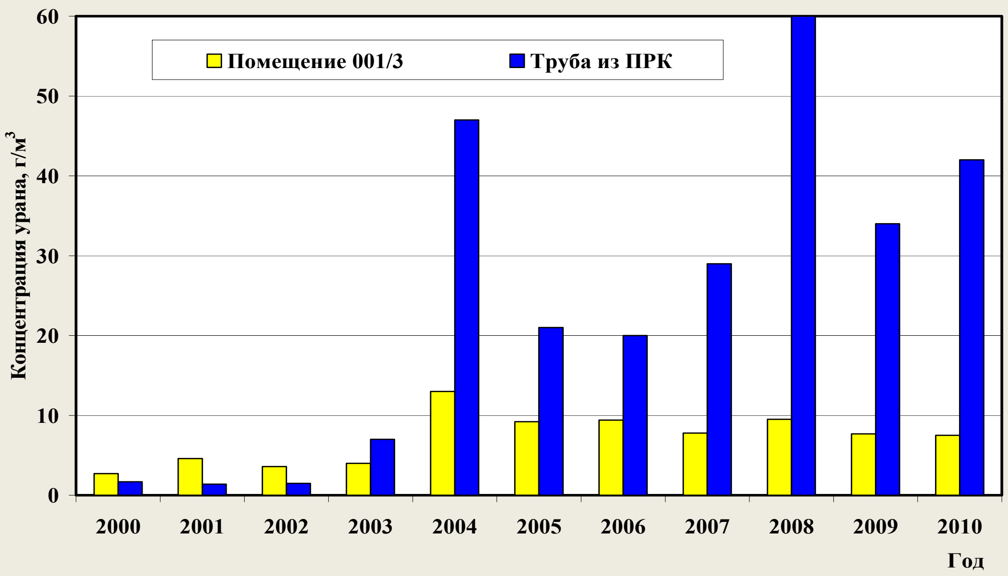


Main sources of water ingress in «Shelter» object rooms

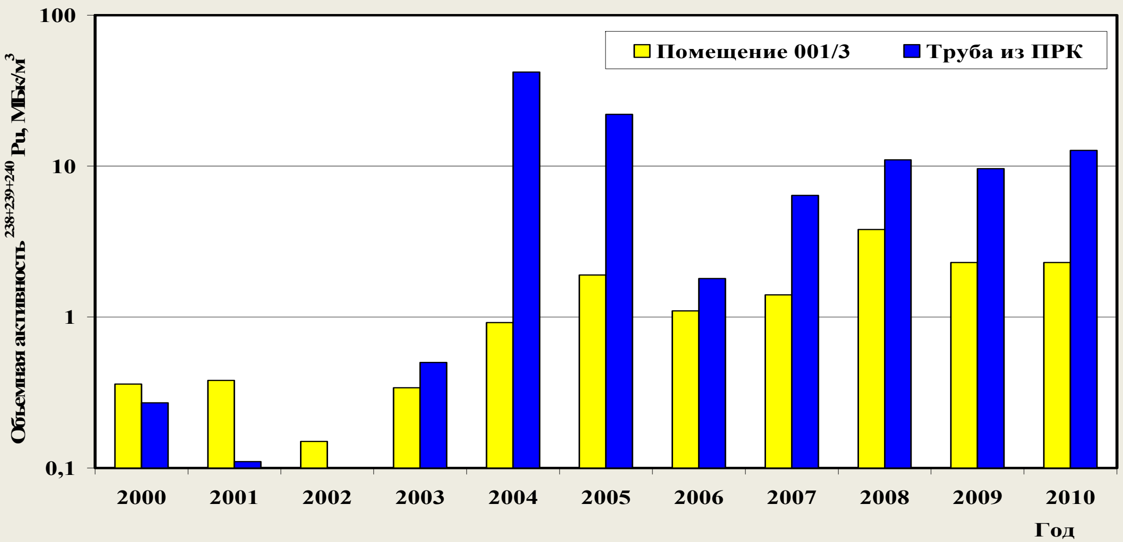
Research of behaviour of uranium, fission products and transuranic elements in SO LRW.



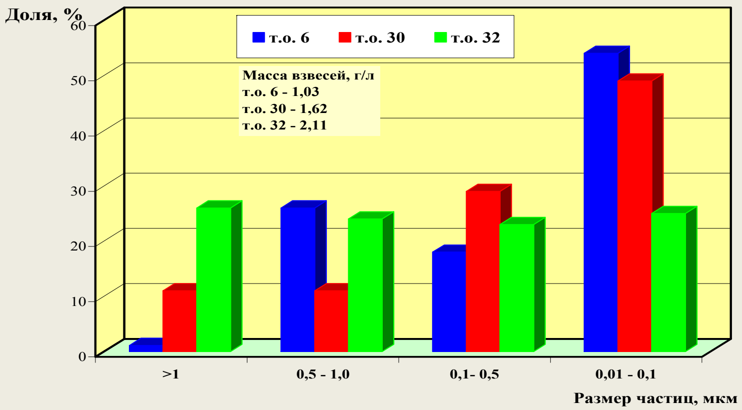
Dynamics of annual average volumetric activity of 90Sr, 238+239+240Pu and 241Am in LRW from SDC (point 20) from 1996 before 2011 years (I – IX month.)



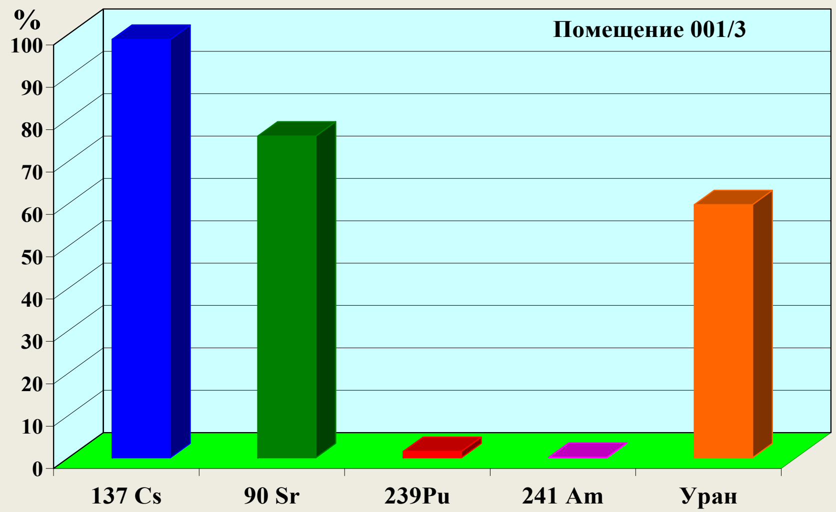
Average annual concentrations of uranium and volumetric activity of plutonium in LRW from SDC (p.20) and room 001/3 (p. 30).



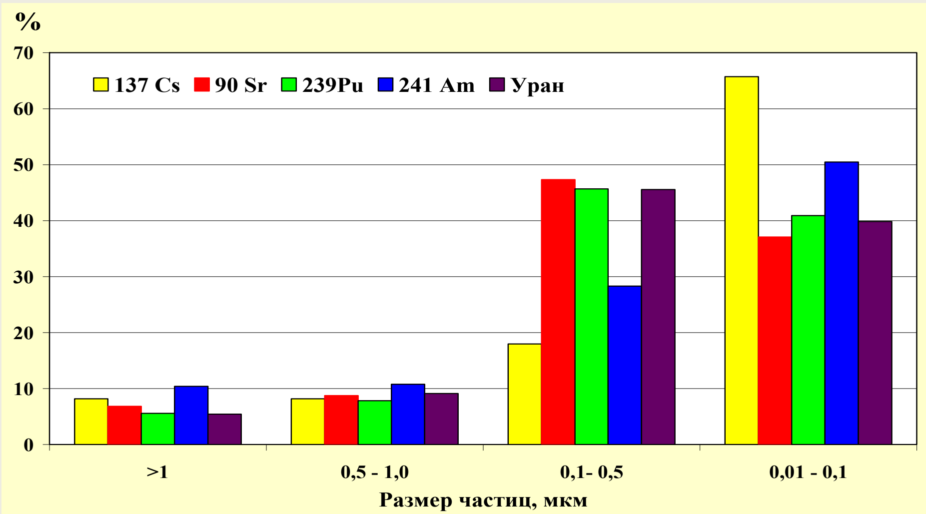
➢Definition of LRW disperse content in SO main water clusters.



Disperse content of LRW solid phase of «Shelter» object

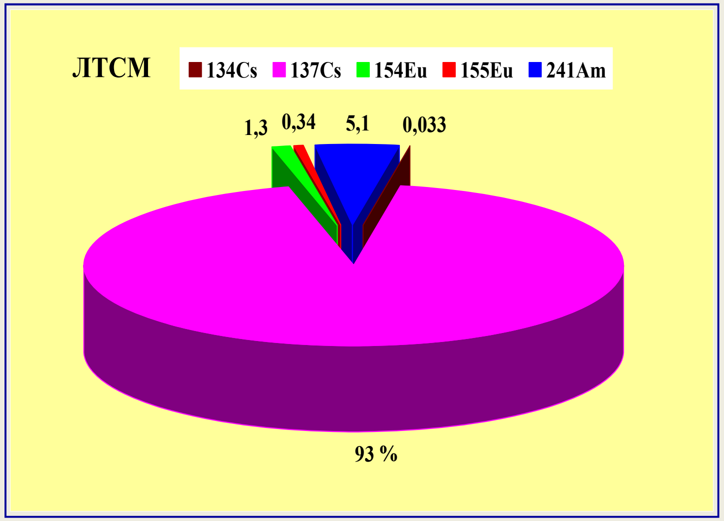


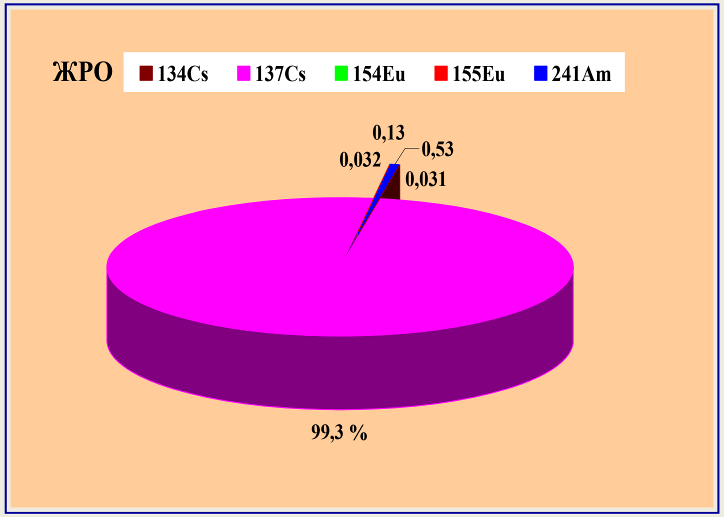
Share of soluble uranium and radionuclides in room 001/3 LRW



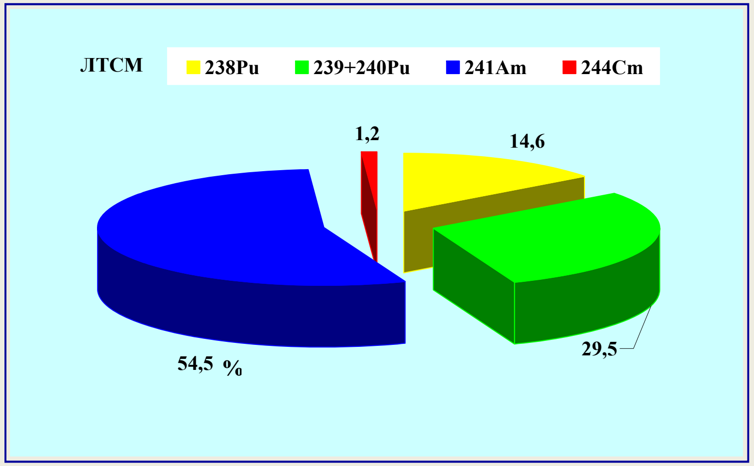
Distribution of radionuclide and uranium activities on solid phase particles of diverse sizes in room 001/3 LRW (sampling point 30).

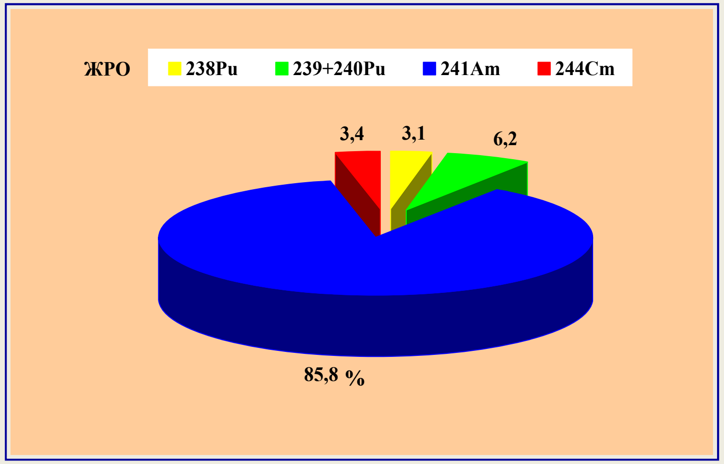
➢ Definition of ratios and features of LRW radionuclide content for evaluation of LFCM degradation degree



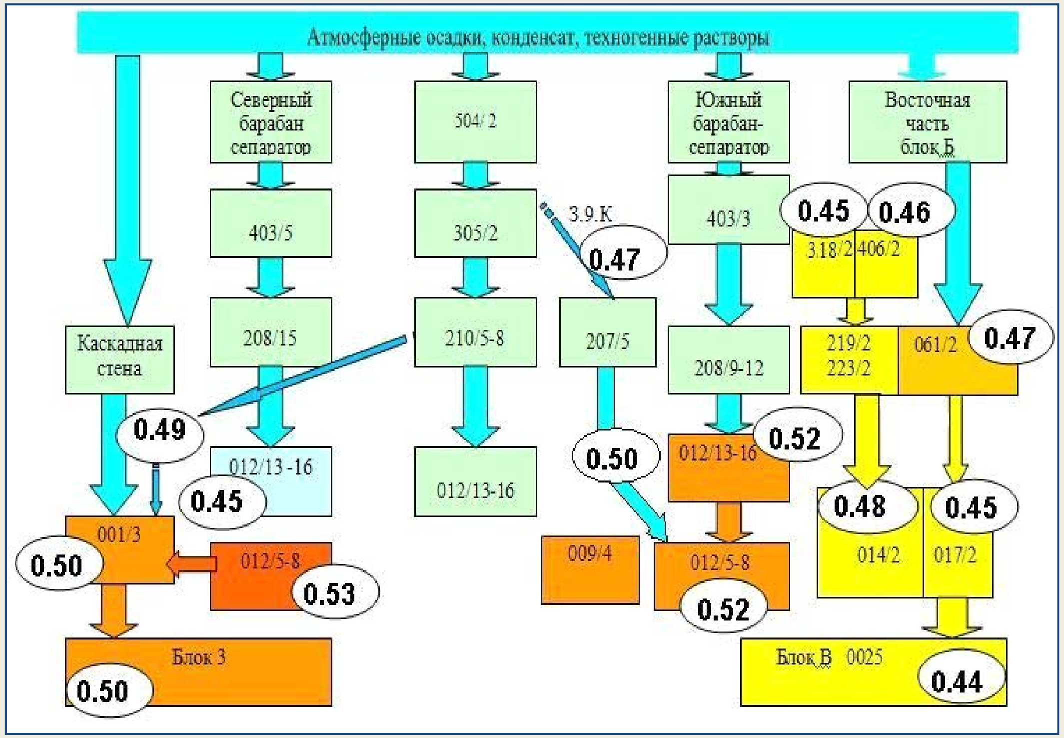


Relative contribution of radionuclides in LFCM and LRW γ-activity





Relative contribution of radionuclides in LFCM and LRW α-activity



Scheme of water flows and clusters with different values of ratio of 238Pu/239+240Pu activities.

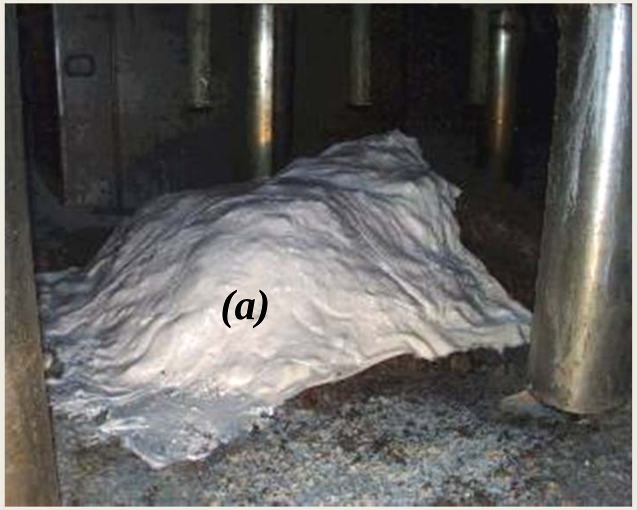
When the water interacts with structural and fuel-containing materials inside «Shelter» object, LRW flows and clusters are produced, which can be referred to medium-active waste categories.
«Shelter» object LRW represents alkaline-carbonate solutions with high content of organic compounds.
The LRW volumes in main non-organized clusters remain, practically, unchangeable during a range of years with considering seasonal changes, and make of order 350 m^3.
A stable tendency is observed of increase in content of uranium, fission products and TUE in SO water leakages and water clusters.
Practically, for each LRW cluster, their specific ratios are typical between different radionuclides.
In the LRW, 244Cm and 241Am shares in TUE summary activity as compared to FCM, are in 5 – 10 fold higher.

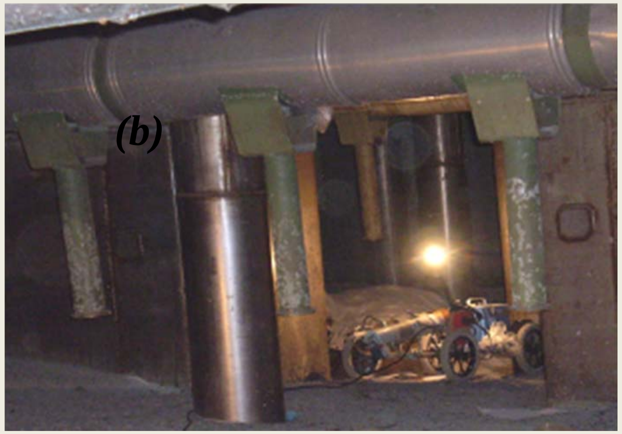
Therefore, the researches of "Shelter" object LRW have shown that in SO, LFCM degradation processes are taking place, and the procedures worked out as a result of RDW realization, concerning LRW monitoring procedure, can be offered to arrange non-operative monitoring of LFCM degradation.

• **Monitoring of environmental radioactive aerosol releases from «Shelter» object**

➢Research of disperse content of SO aerosols

• Study of disperse content of radioactive aerosols – LFCM degradation products in close vicinity from their clusters. PSP-1 room 012/17





FCM cluster in room 012/17 PSP-1 (a) and device (b) for RA remote sampling.

1. Open FCM clusters degrade and constantly generate the RA.
2. Activity of aerosols-carriers of beta-emitting nuclides sum in room 012/7, in close vicinity from FCM cluster, had changed in 2008 – 2011 years within the range from 4,0 before 100 Bq/m³.
3. Main radionuclide ratios in sampled aerosols made as follows: 137Cs/241Am = 17; 241Am/154Eu = 5,0; 137Cs/154Eu = 80 and are typical for FCM specimens from this room namely.
4. Dispersity of aerosols: AMAD ≥ 2 mkm.

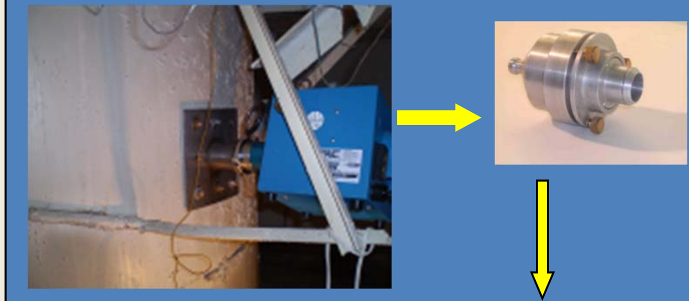
Averaged results of analyses of LFCM cluster samples in room 012/7 (as of July 19, 2011

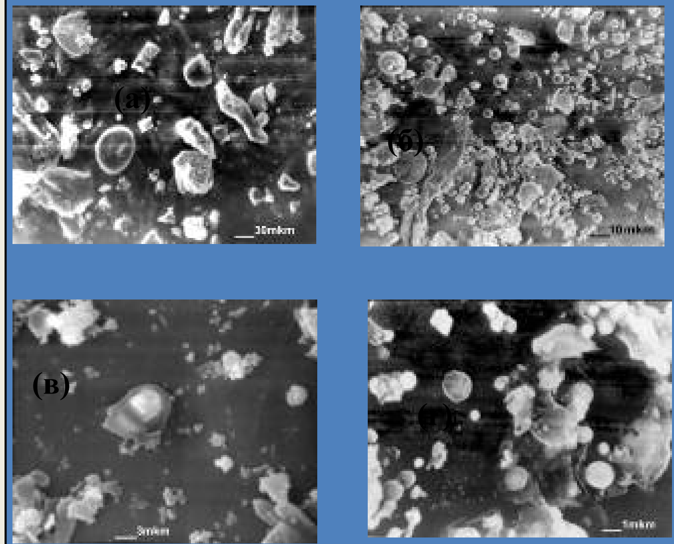
^{137}Cs	^{154}Eu	^{155}Eu	^{241}Am	^{90}Sr	^{238}Pu	$^{239+240}$Pu
$(2,1\pm0,29)\cdot10^{7}$	$(3,8\pm0,53)\cdot10^{5}$	$(6,9\pm1,6)\cdot10^{4}$	$(1,8\pm0,25)\cdot10^{6}$	$(3,7\pm1,1)\cdot10^{7}$	$(4,7\pm0,94)\cdot10^{5}$	$(9,8\pm0,20)\cdot10^{5}$
^{137}Cs/^{241}Am	^{137}Cs/^{154}Eu	^{241}Am/^{154}Eu	^{154}Eu/^{155}Eu	^{137}Cs/^{90}Sr	^{90}Sr/^{241}Am	^{241}Am/$^{238+239+240}$Pu
12 ± 2,3	55 ± 11	4,7 ± 0,9	5,5 ± 1,5	0,57 ± 0,19	21 ± 6	1,24 ± 0,24

5. Probe-tested procedure of RA remote sampling in close vicinity to FCM clusters is effective and can be proposed as an element of non-operative monitoring of degradation for other open FCM clusters.

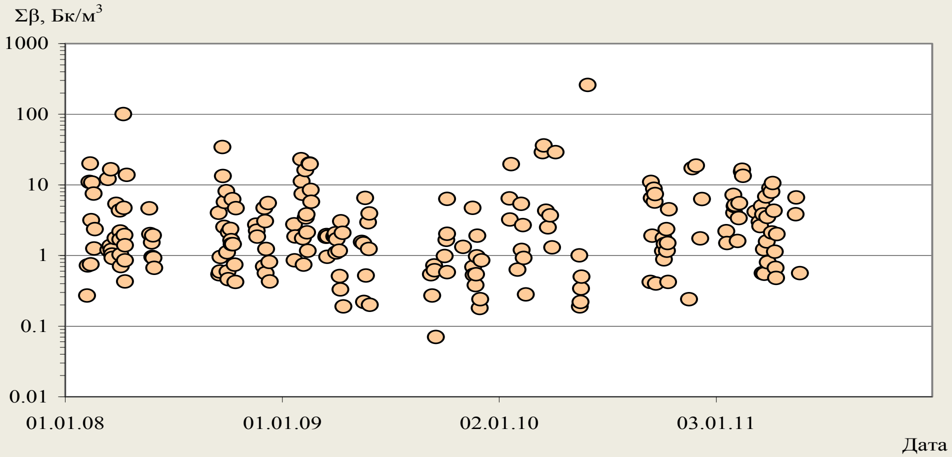
• Disperse content of radioactive aerosols in "Bypass" system

Device for aerosol sampling in "Bypass" system

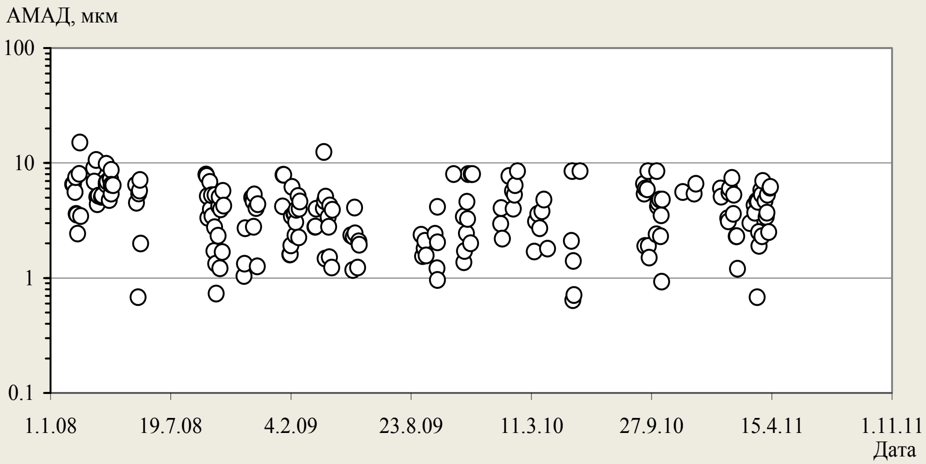




Morphology of particles: in first (a), second (b), third (c), and fourth (d), impactor cascades.

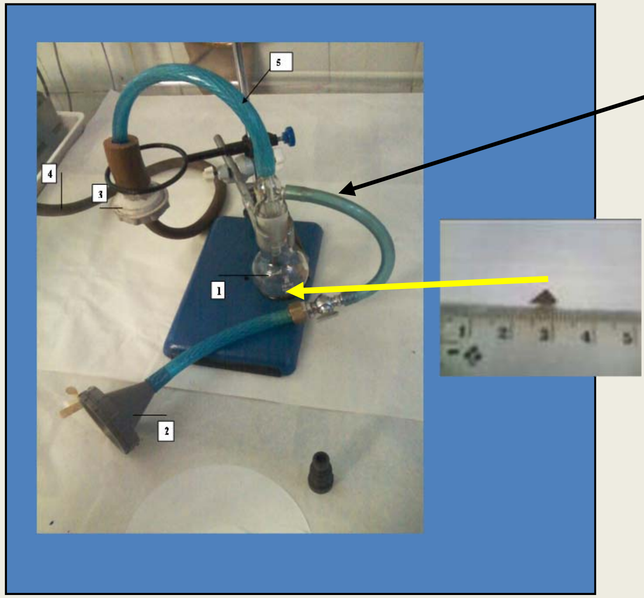


Concentration of β-emitting aerosols mix - accident products (∑β) in SO "Bypass" system SO in 2008 – 2011 years.



AMAD of radionuclide carriers - Chernobyl accident products in SO "Bypass" system in 2008 - 2011 years.

•Disperse content of radioactive aerosols – LFCM degradation products



Device for radioactive aerosol analysis by procedure of blowing from surface of LFCM (brown)

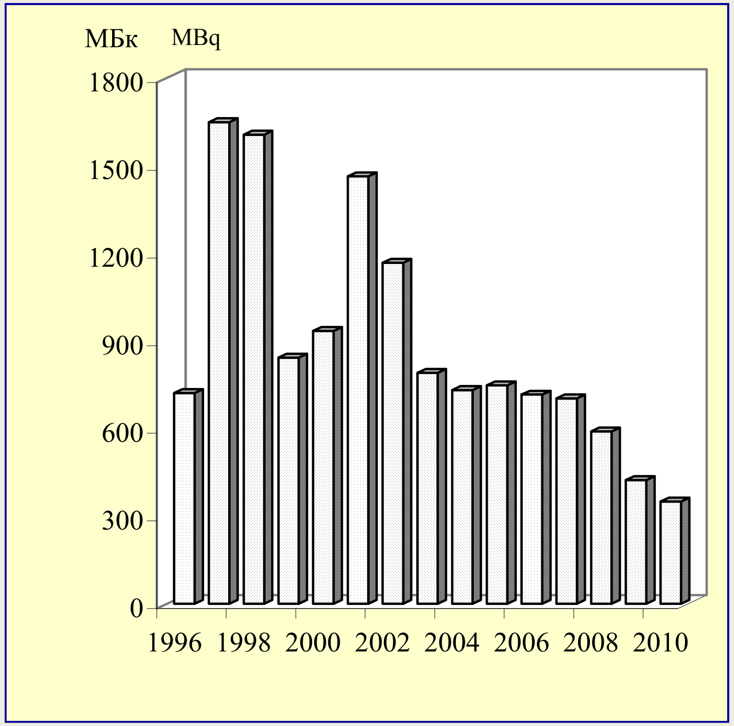
Dispersity of aerosols: AMAD ≥ 2 mkm.
Wind erosion velocity of brown LFCM under air blowing in laboratory conditions makes 19 mkg/(cm^2·year).
Result obtained is higher, approximately two orders of value, than that received in analogous experiment conducted in 1990 year for brown LFCM, in terms of 137Cs and 90Sr activities.

Results of gamma-spectrometry analysis of brown LFCM (as of January 20, 2010)

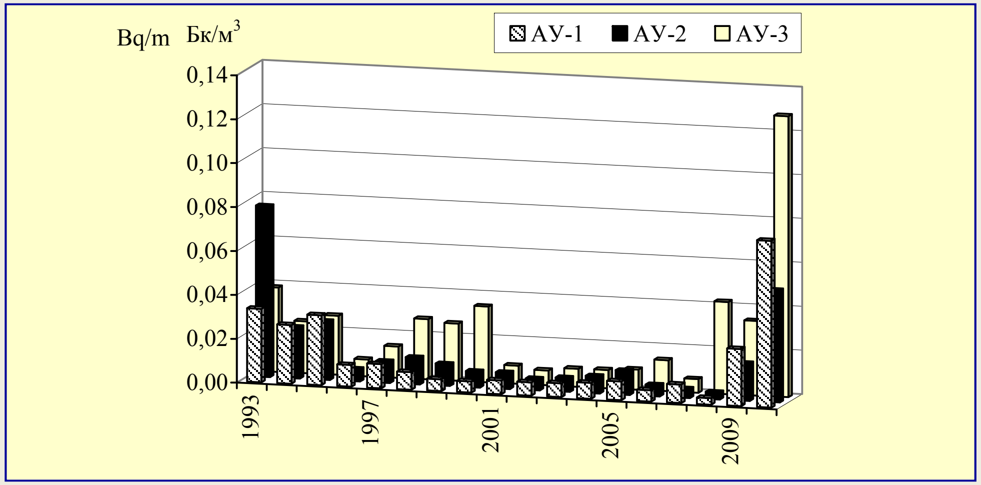
Активность ± ошибка, Бк/проба (при P = 0,95)				^{137}Cs / ^{241}Am	^{137}Cs / ^{154}Eu	^{241}Am / ^{154}Eu	^{154}Eu / ^{155}Eu
^{137}Cs	^{154}Eu	^{155}Eu	^{241}Am				
$(9{,}9\pm0{,}65)10^{6}$	$(9{,}9\pm0{,}92)10^{4}$	$(1{,}9\pm0{,}39)10^{4}$	$(5{,}1\pm0{,}67)10^{5}$	19	100	5,2	5,2

Results of gamma-spectrometry analysis of double filter (recount for January 20, 2010)

Активность ± ошибка, Бк/проба (при P = 0,95)				^{137}Cs / ^{241}Am	^{137}Cs / ^{154}Eu	^{241}Am / ^{154}Eu	^{154}Eu / ^{155}Eu
^{137}Cs	^{154}Eu	^{155}Eu	^{241}Am				
$9{,}810^{2}\pm8{,}2$	$9{,}8\pm0{,}3$	$2{,}3\pm0{,}3$	$52\pm5{,}0$	19	100	5,3	4,3



Radioactive aerosol releases via «Shelter» object leakages



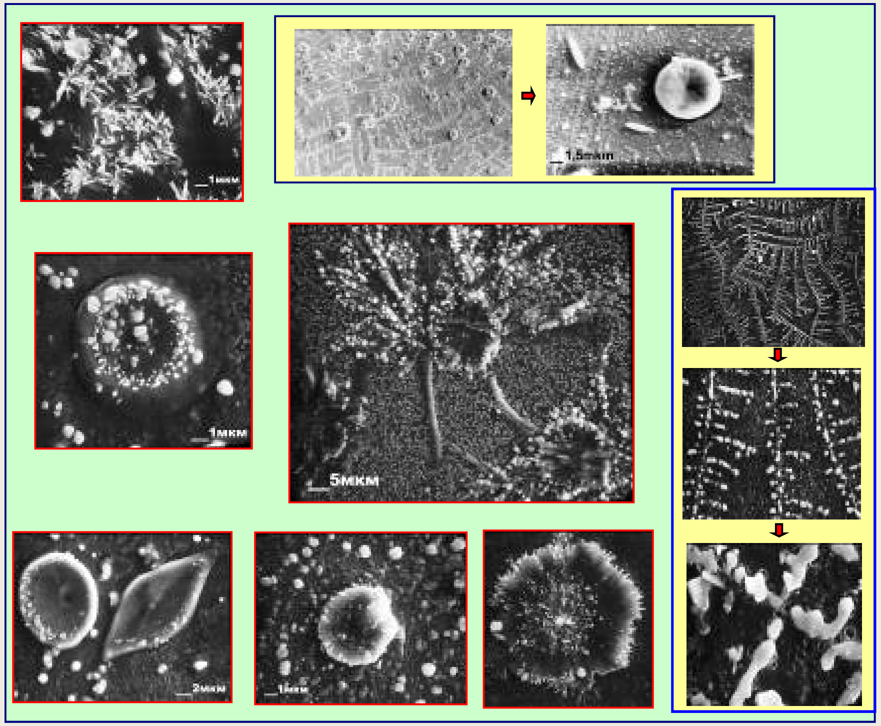
Radioactive aerosol concentration in surface layer of «Shelter» object

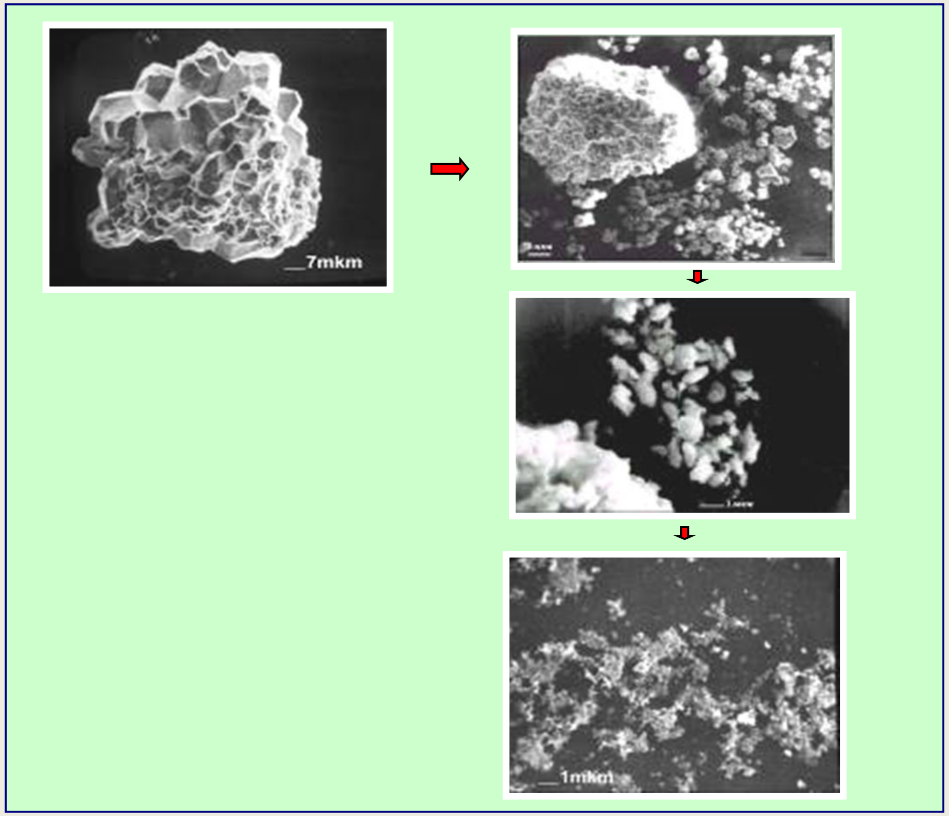
1. The carriers of radionuclides – Chernobyl accident products are the particles with AMAD 2 – 5 mkm.

2. In the content of beta-active aerosols being released in atmosphere via the system a third part belongs to ^{137}Cs, that corresponds to Unit 4 fuel base content in 2008 – 2011 years:
^{137}Cs (33 %), ^{90}Sr + ^{90}Y (each has 27 %), ^{241}Pu (12 %).

3. The particles with AMAD less than 1 mkm have organic nature of origin and, it is not excluded, they are the microbiological «corrosion» products of INF.

•Influence of biotic factor to destruction degree of SO irradiated nuclear fuel (INF)

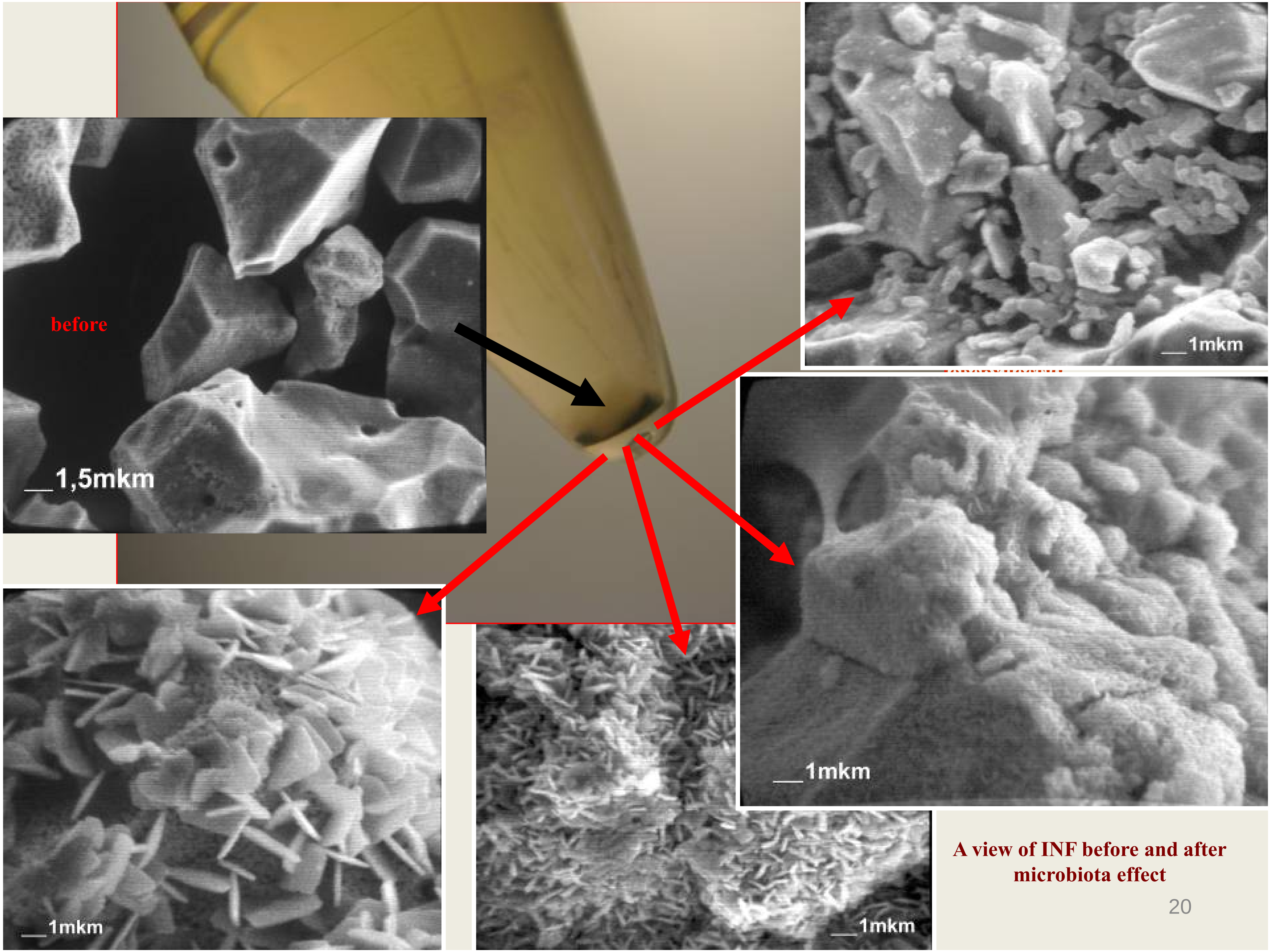




Sources for separation of microrganism (MO) cultures:
- SO LRW (room …p. 6, 20, 32,3 5).
- Elective nutrients – more 10 nurture groups.

INF destruction process under biotic factor impact:

1. Initial INF particle
2. Invasion of INF particles with MO culture and surface degradation - 30 days
3. Decay in crystal grains
4. Dilution of crystal grains - from 30 before 90 days
5. Total dilution of INF MO



A view of INF before and after microbiota effect

• In the specimens of SO LRW, a wide variety of microorganism forms was detected. Amount of cultures capable to dilute the INF, in some species groups separated of SO LRW, reaches 90%.

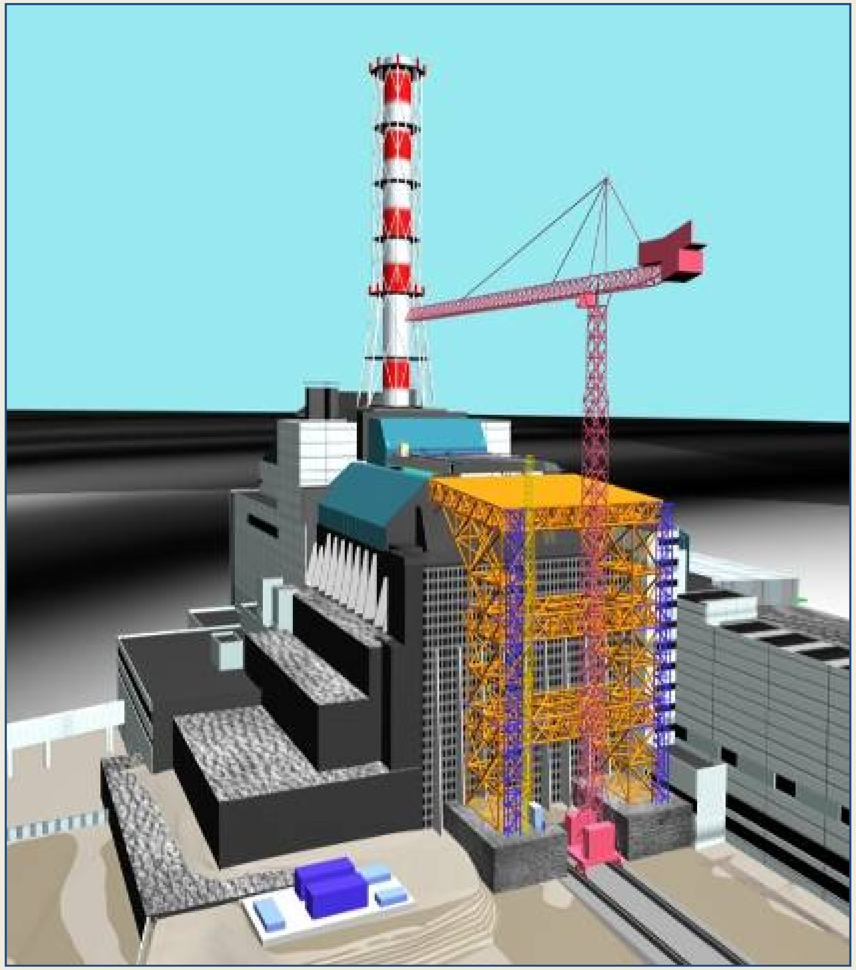
• As a result of INF microbial corrosion, complex compounds of r/n are produced, whose 97-98% are bound by organic substance. More than 70 % obtained microbial metabolites firmly bind Sr and Cs simultaneously. Content of r/n in biomass reaches 10E+8 Bq/g for Cs-137 or Sr-90.

• Microorganism symbioses entail the changes of not only the amount of mobile water-soluble forms of radionuclides, but it changes also qualitative content of microbial metabolites, their properties and migration characteristics. Under long-term effects of ionizing radiation (INF), proteins with new bounding properties appear in the cultures1.

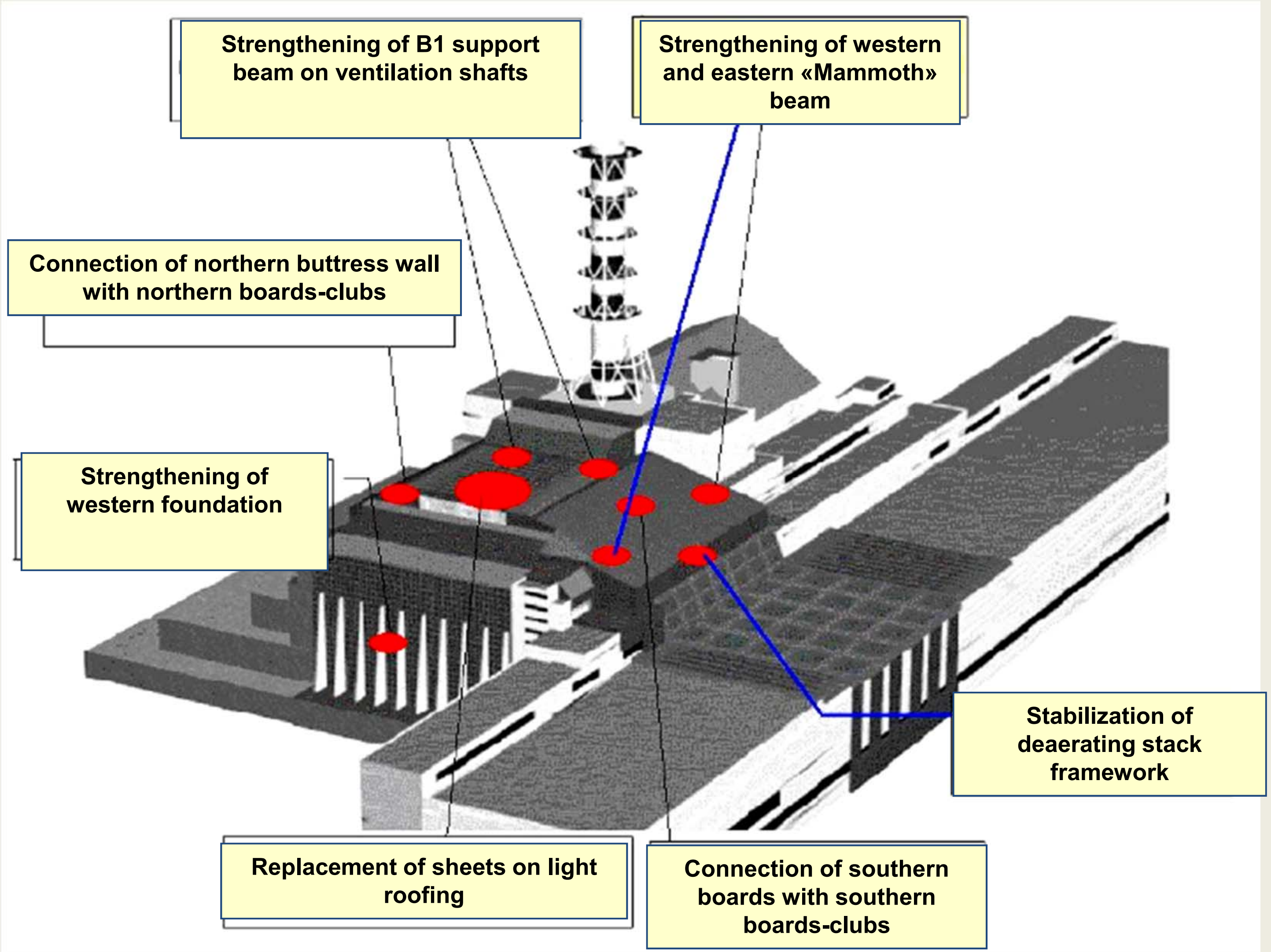
•When INF particles penetrate in favourable environmental conditions, they can be diluted by microorganisms during several years with producing mobile radionuclide forms.

• Microorganisms may be used in procedures for handling of LRW and SRW, decontamination of natural and technogenic objects.

Stabilization of building structures of «Shelter» object.

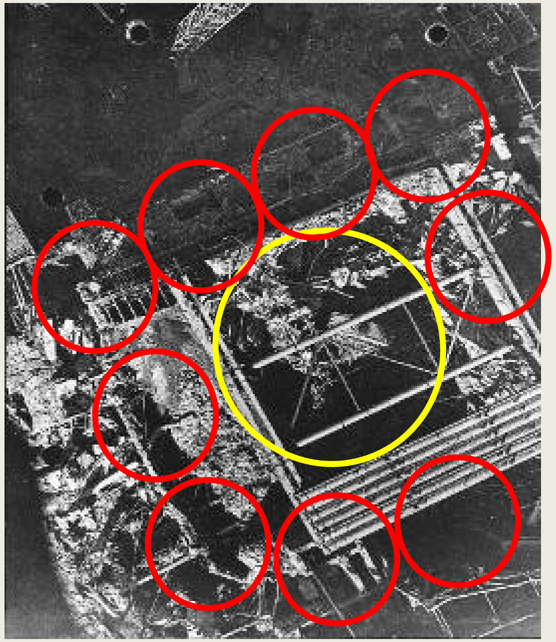


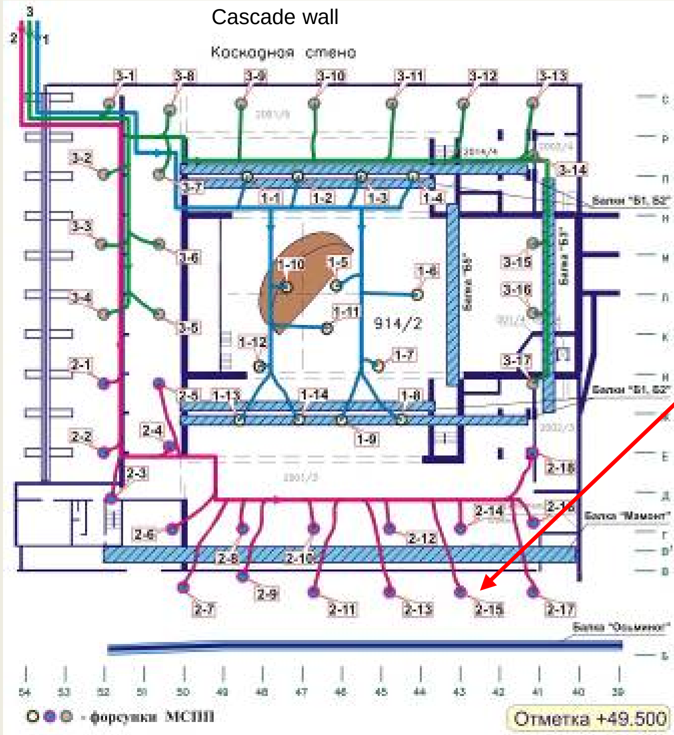
The works for SO building structures' stabilization were aimed at excluding of probability of potential accidents associated with destruction of building structures and prolonging the lifetime of «Shelter» safe operation (15 years) before the completion of New Safe Confinement erection.
Realization of this project has allowed reducing the scope of work for Ukrainian entities, including also for our Institute.



«Shelter» object areas, in which the measures to stabilize building structures were realized

Commission of modernized system for suppression and fixation of radioactive aerosols in sub-roofing space of «Shelter» object.





- Dust suppression system of 1989 y.

- Modernized dust suppression system

Modernized dust suppression system :
49 nozzles, plume diameter -14 m.

Protective film on sub-roofing space surfaces of «Shelter» object after dust suppression system work.

The commission of dust suppression system had allowed fixing the radioactive dust on surfaces of sub-roofing space of «Shelter» object.
To reduce radioactive aerosol releases into the environment.
To improve radiation safety of personnel, including of those working for stabilization of building structures.
On top of that, the system was applied for inserting neutron-absorbing materials (NAM) - 0,1% gadolinium solution in FCM clusters. Today, the system is a single means of delivery of gadolinium solution in CH eastern part (nuclearly hazardous area), where «fresh» fuel is located.

Research works inside the «Shelter» object

Propositions to convert technogenic radiation-hazardous emergency objects in ecologically safe system

1.First stage. Development of measures to monitor the behaviour of radioactive materials (RM) produced as a result of technogenic accidents:

1.1. Development of decision making criteria pursuant to RM for reduction of current and potential negative impacts for personnel and environment. Identification of data volume and assessments of current and forecast state of RM needed for decision making when developing the strategy of RM retrieval and burial.

1.2. Development of procedures and means for data obtaining and estimates of current and forecast state of RM based on monitoring results:

- ***radiation parameters of RM clusters;***
- ***radiation parameters of air medium contamination;***
- ***radiation parameters of LRW.***

1.3. Definition of volume for monitoring the state of building structures, in which the RM clusters are located, and definition of criteria of potential radiation hazard during their displacement or collapse.

1.4. Definition of volume for monitoring the state of building structures, in which the RM clusters are located, and definition of criteria of potential nuclear hazard during their displacement of collapse.

1.5. Development of methodology and software for database creation, which allow making accumulation and storage of monitoring results, their analysis, obtaining of data and assessments of current and forecast state of RM behaviour with considering reference and critical safety levels.

1.6. Development of conceptual project of preventive actions system for nuclear and radiation safety of RM.

2. Second stage. Development of measures (actions) for period before termination of development of strategy for RM retrieval and management:

2.1. Realization of RM state monitoring based on scope specified at the 1-st stage.

2.2. Carrying out of estimates of structure conditions of rooms and facilities, in which the RM are located. Assessment of nuclear and radiation hazard of RM during their displacement or collapse.

2.3. Realization of program of current and forecast state of RM.

2.4. Realization of RM research works by way of sampling and study of specimens.

2.5. Development of models of RM behavior forecasting for long-term period.

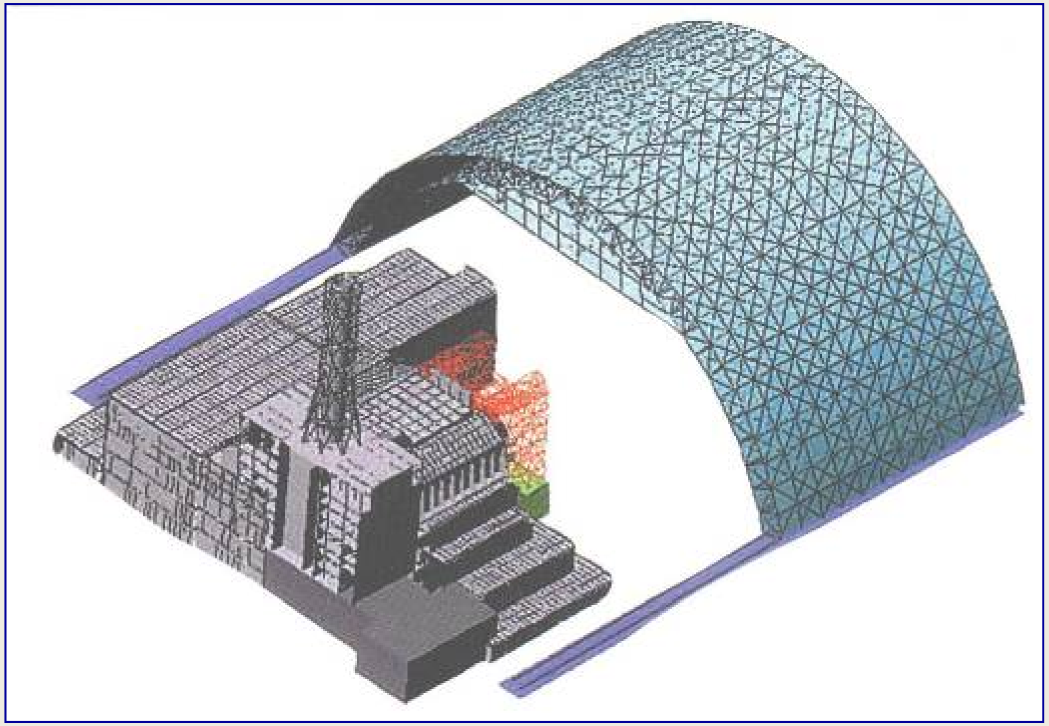
2.6. Development of RM retrieval and management strategy.

3. Third stage. Development of measures (actions) for period of RM retrieval and management:

3.1. Development of program of long-term monitoring of RM behaviour at their retrieval stage.

3.2. Realization of program of long-term monitoring of RM behaviour at their retrieval stage.

New Safe Confinement



Main sizes:

- •Span – 257 m,
- •Length – 150 m,
- •Height – 108 m,
- •Weight – 22 000 t,
- •Cranes – 4, each 50 t,
- •Lifetime – 100 years

«New Safe Confinement – is a protective structure including a complex of process equipment for:

➢Retrieval from ruined Chernobyl NPP power Unit 4 of materials containing the nuclear fuel;

➢Radwaste management;

➢Conversion of this Unit into an ecologically safe system and provision of safety for Plant personnel, public and environment.

Clearing the site for New Safe Confinement

- RM removed on site for temporary stockpiling of grounds – 2179 m^3;
- SRAW removed in PBRW «Buriakivka» - 31,7 m^3.
- Demolition with concrete breaker with loading – 239 m^3;
- Development of technogenic back filling – 1230 m^3;

New Safe Confinement Conceptual Desing

Thank You for attention